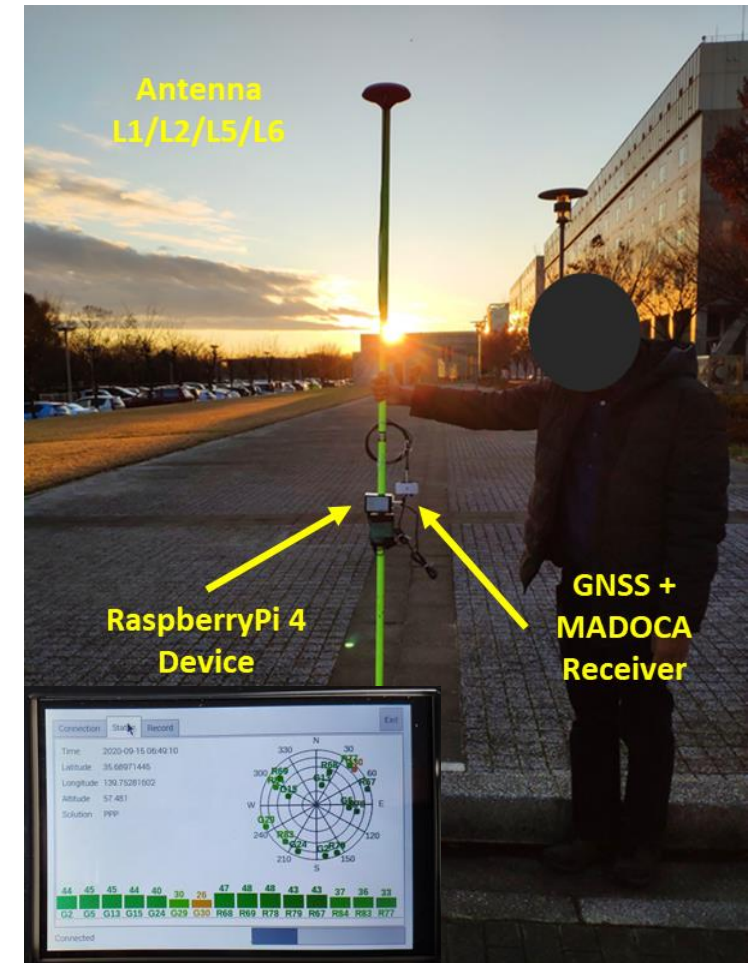


Low-Cost High-Accuracy GNSS Receiver Systems

(A) Based on RTK/PPK
(B) Based on MADOCA

Dinesh Manandhar
CSIS, The University of Tokyo
dinesh@csis.u-tokyo.ac.jp
28th January 2021

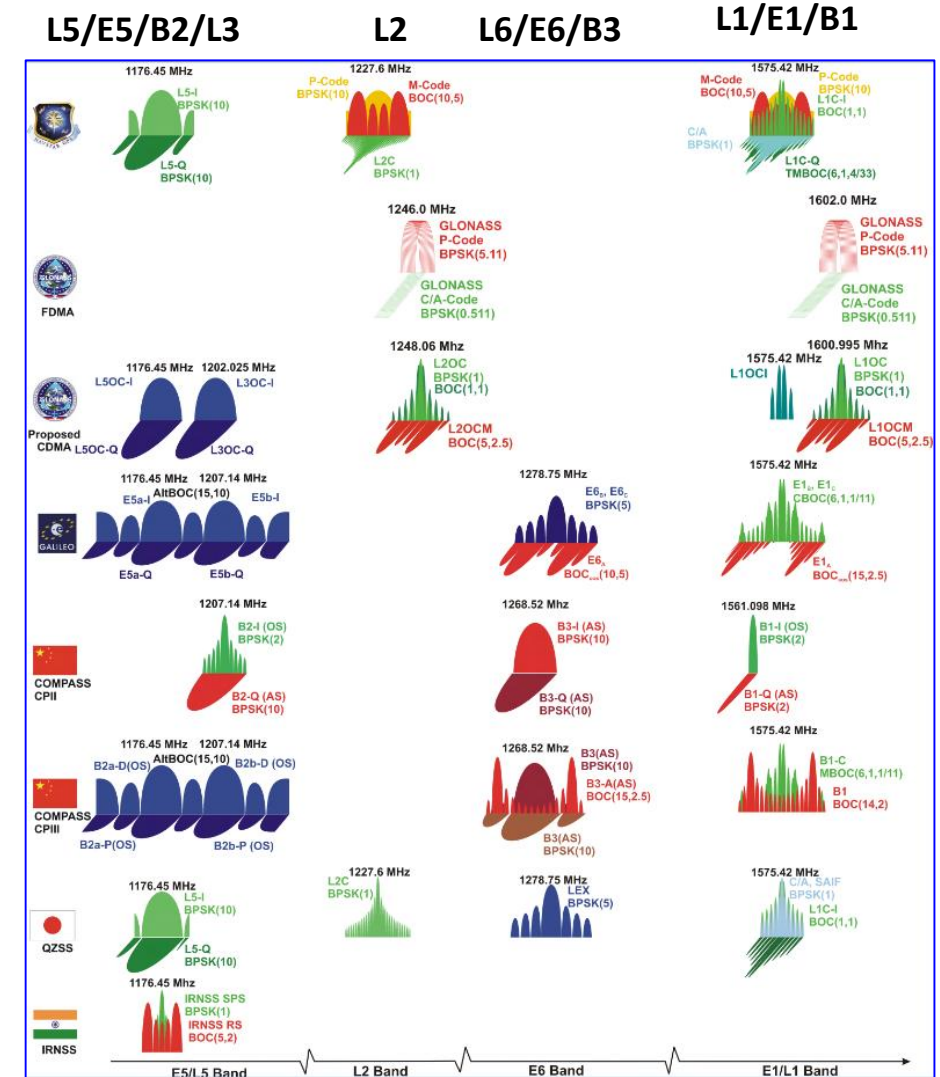


Quiz

- What is the Price of a GNSS Receiver?
 - \$10? / \$100? / \$500 / \$1,000 / \$3,000 / \$10,000 or more?
- What is the Accuracy that you can get from a GNSS receiver?
 - mm, cm, dm, few meters or 10 – 30m
- But, what are your requirements?
 - Types of Applications
 - Accuracy Requirements
 - Data Logging Methods
 - Static Mode on a Tripod
 - Dynamic Mode on a Car, Tractor or Machine?
 - Real-Time or Post-Processing

High-End Survey Grade Receivers

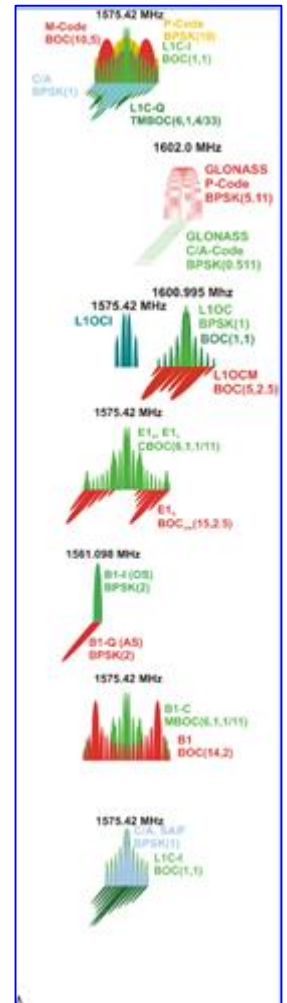
- Multi-frequency
 - GPS : L1/L2/L5
 - GLONASS : L1/L2/L3
 - GALILEO : E1/E5/E6
 - BDS : B1/B2/B3
 - QZSS : L1/L2/L5/L6
 - NAVIC : L5/S
- Multi-system
 - GPS, GLONASS, GALILEO, BeiDou, QZSS, NAVIC, SBAS etc
- Price varies from \$3, 000 to \$30,000 or more



Low-Cost Receivers

- Multi-System
 - GPS, GLONASS, GALILEO, BeiDou, QZSS, SBAS etc
- Basically Single Frequency
 - L1/E1/B1-Band
 - Very soon: Multi-System, Multi Frequency, L1/L2 or L1/L5
 - Future trend for Mass Market System will be L1/L5
 - Some chip makers have already announced Multi-System, Multi-Frequency GNSS Chips for Mass Market
- Low Cost:
 - Less than \$300 (Multi-GNSS, L1 Only) including Antenna and all necessary Hardware, Software
 - Our target is within \$100 or less including everything

L1/E1/B1*



*Note: Only one signal type from each system is processed
e.g. GPS has L1C/A and L1C in L1, ,but only L1C/A is used in Low-Cost Receiver

Our Definition of Low-Cost Receiver

- Price : \$100 or less
- Accuracy : Better than 100cm
- Weight : 100g or less
(Without Battery)

100^3

\$100 x 100cm x 100g

Will it be possible?

Many Applications require
Low-Cost, Small-Size & Low-Power
Receiver System

But, is it possible to get
High-Accuracy with Low-Cost Receivers?

Question?

Although the Normal Accuracy of GPS is about 10m,
why can we get Centimeter Level Accuracy?

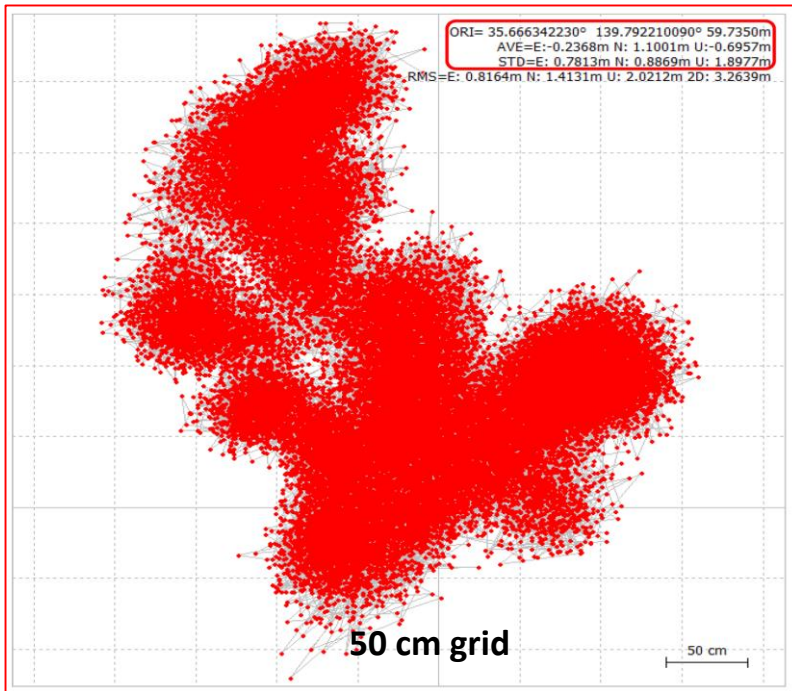
GPS Position Accuracy

How to achieve accuracy from few meters to few centimeters?

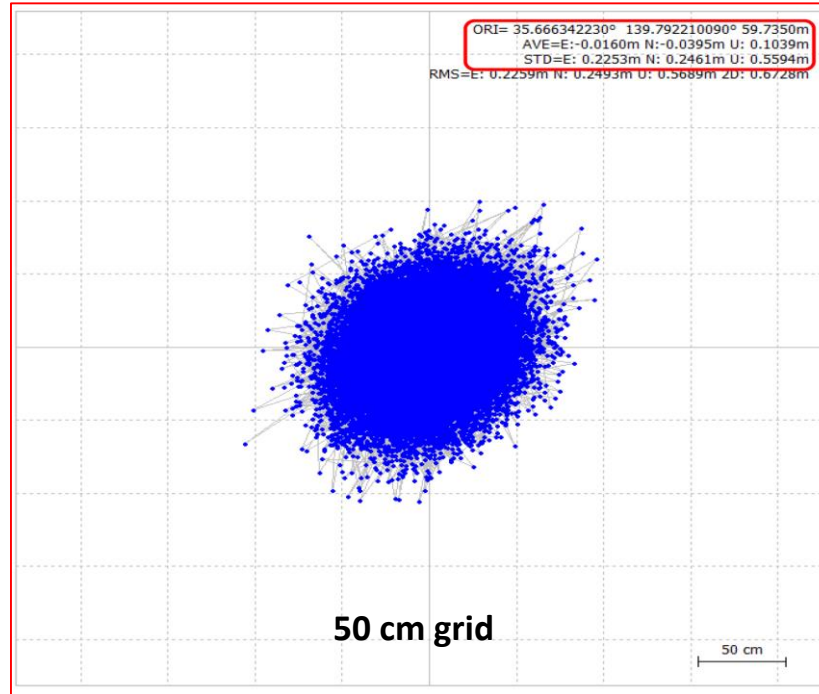
meter



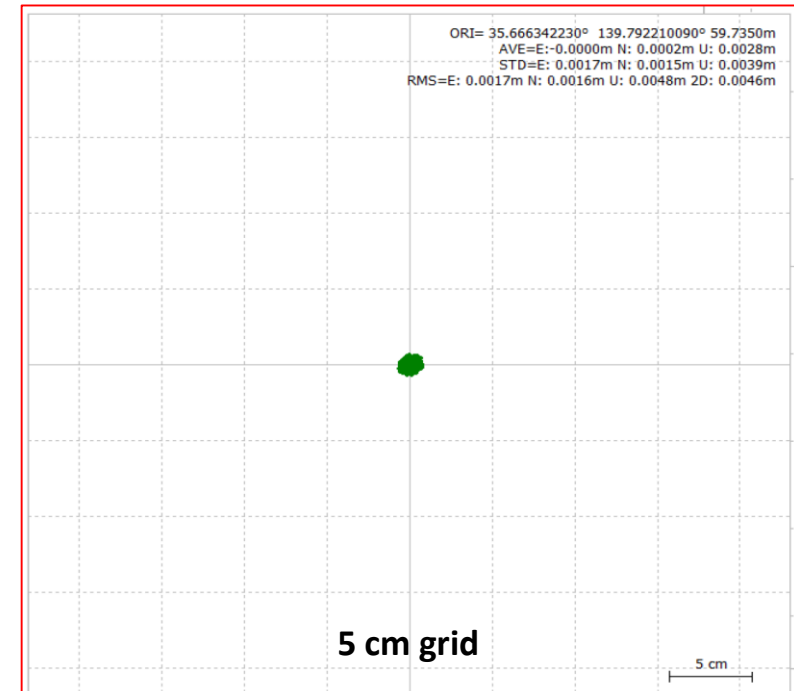
centimeter



SPP (Single Point Position)



DGPS (Differential GPS)
Code-phase observation



RTK (Real Time Kinematic)
Carrier-phase observation

Errors in GPS Observation (L1C/A Signal)

Error Sources	One-Sigma Error , m		Comments
	Total	DGPS	
Satellite Orbit	2.0	0.0	Common errors are removed
Satellite Clock	2.0	0.0	
Ionosphere Error	4.0	0.4	Common errors are reduced
Troposphere Error	0.7	0.2	
Multipath	1.4	1.4	
Receiver Circuits	0.5	0.5	

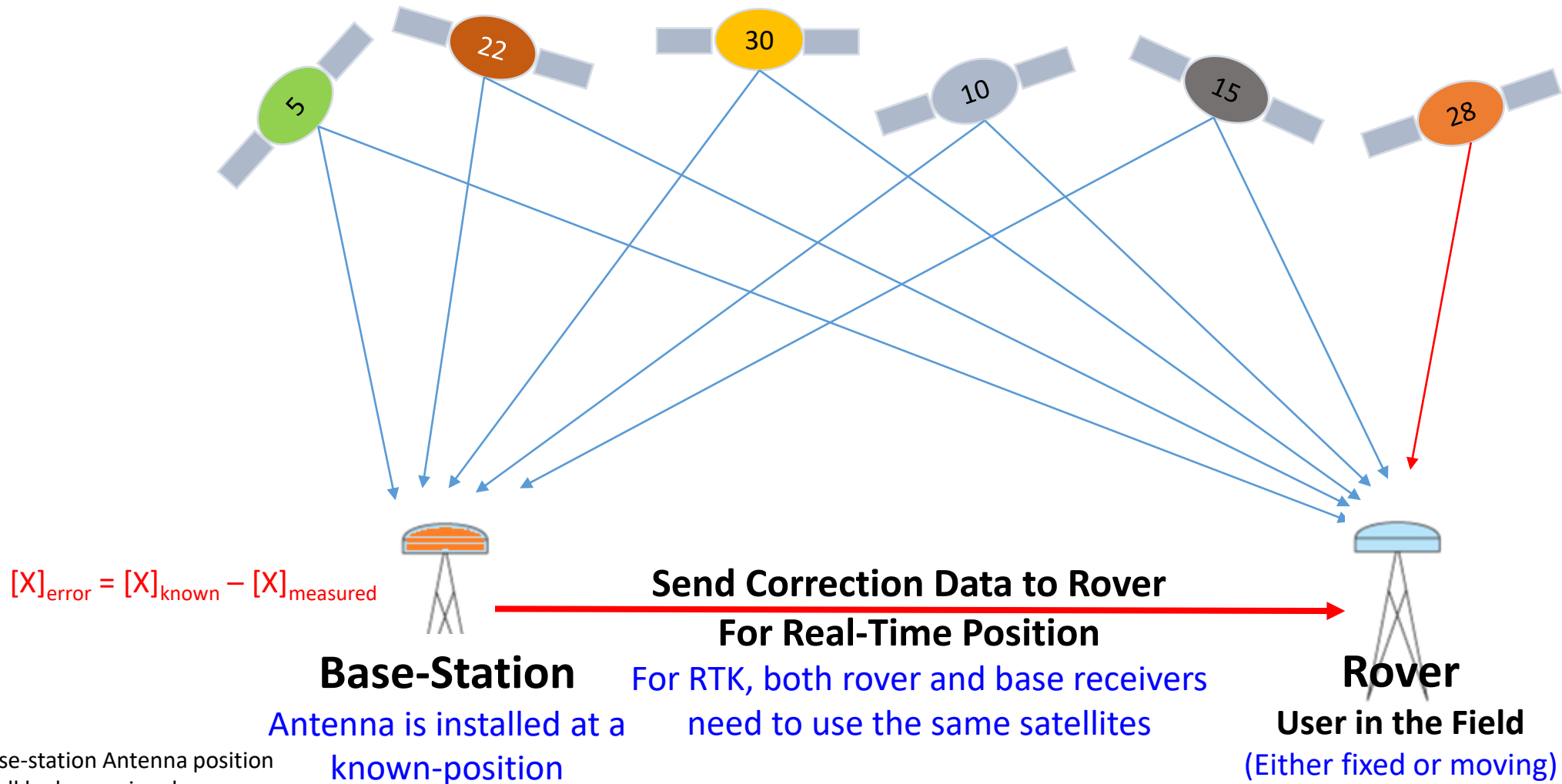
If we can remove common errors, position accuracy can be increased.

Common errors are: Satellite Orbit Errors, Satellite Clock Errors and Atmospheric Errors (within few km)

Values in the Table are just for illustrative purpose, not the exact measured values.
Table Source : http://www.edu-observatory.org/gps/gps_accuracy.html#Multipath

How to Remove or Minimize Common Errors?

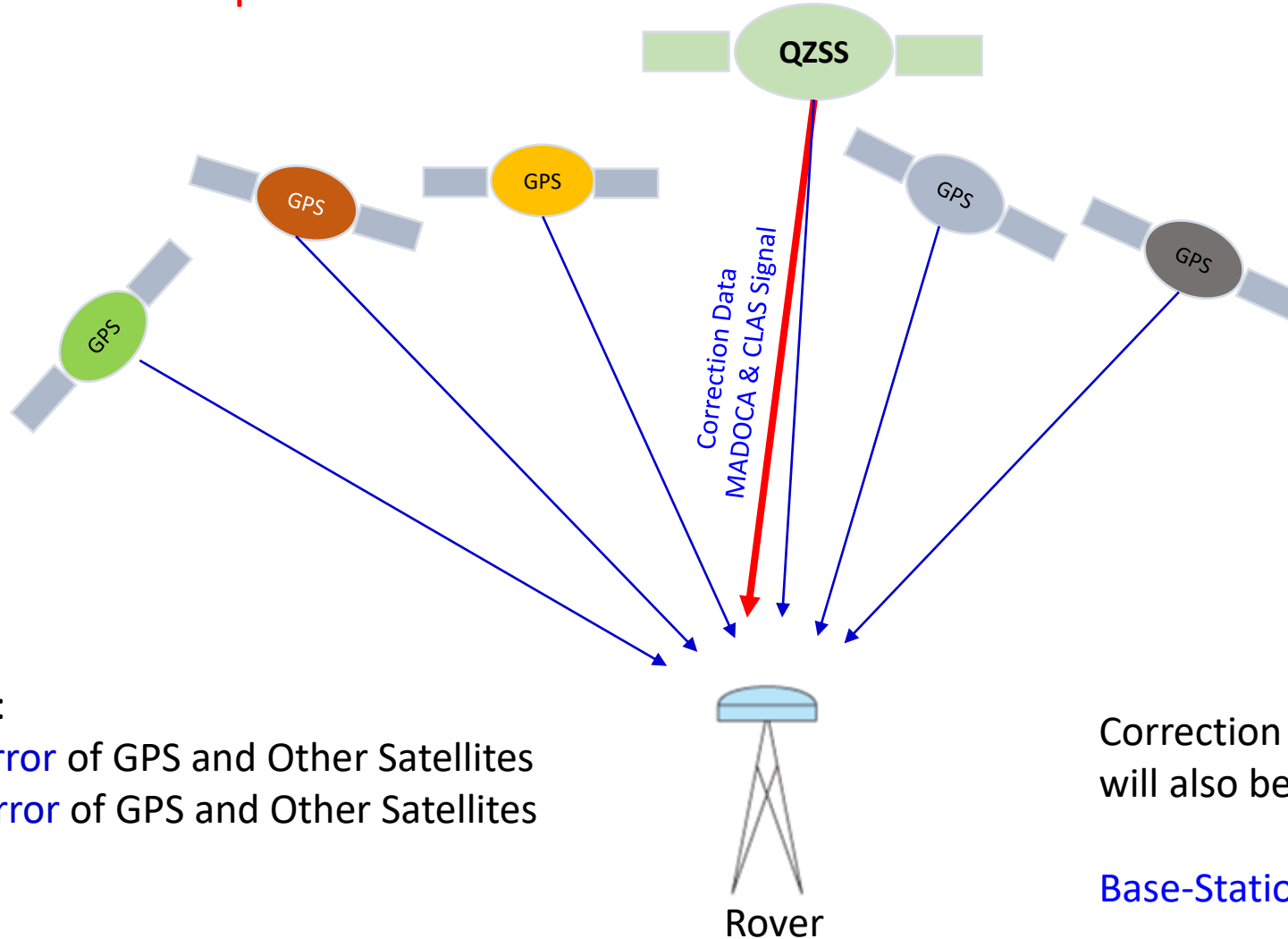
Use Differential Correction



Base-station Antenna position shall be known in advance

How to Remove or Minimize Common Errors?

Principle of QZSS MADOCA and CLAS Services



Correction Data:

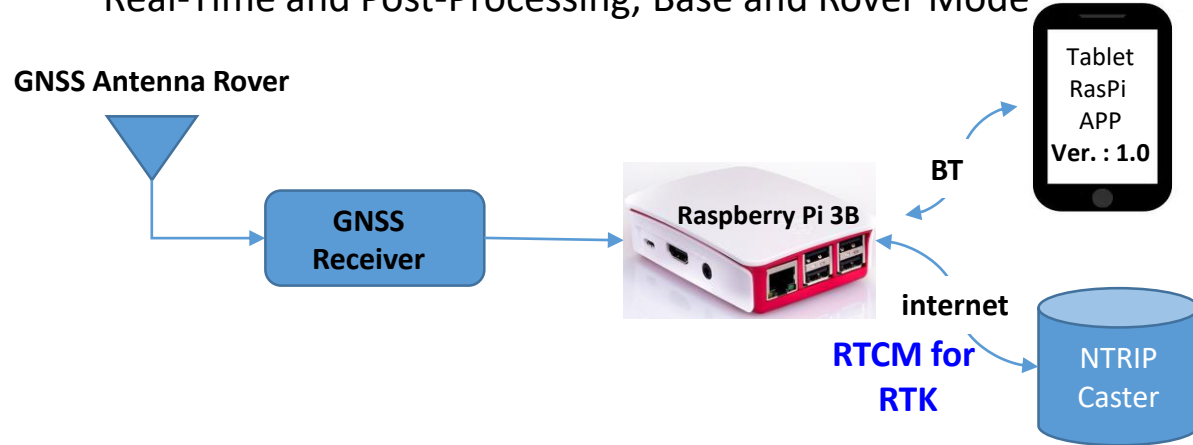
Satellite Orbit Error of GPS and Other Satellites
Satellite Clock Error of GPS and Other Satellites

Correction data for other satellites
will also be provided

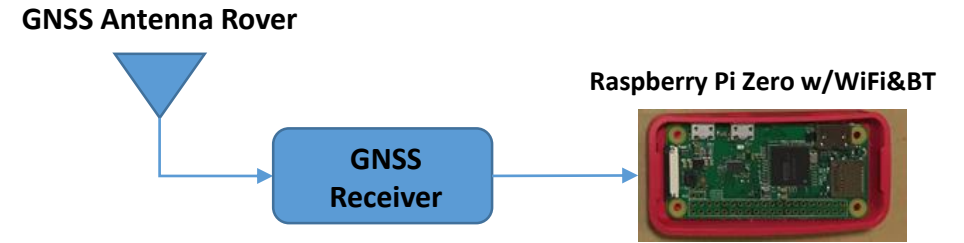
Base-Station not required

Low-Cost RTK Receiver System

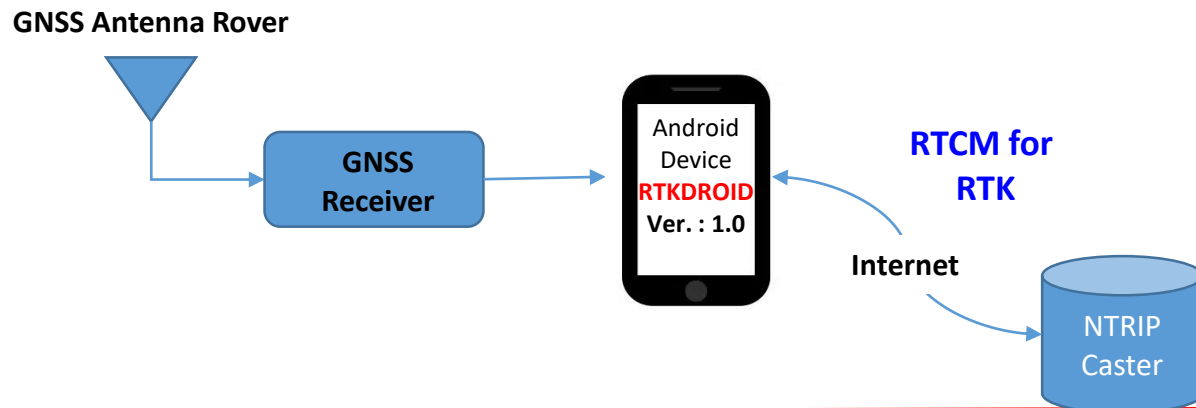
TYPE R1 Type A: Low-Cost, High-Accuracy Receiver System
Real-Time and Post-Processing, Base and Rover Mode



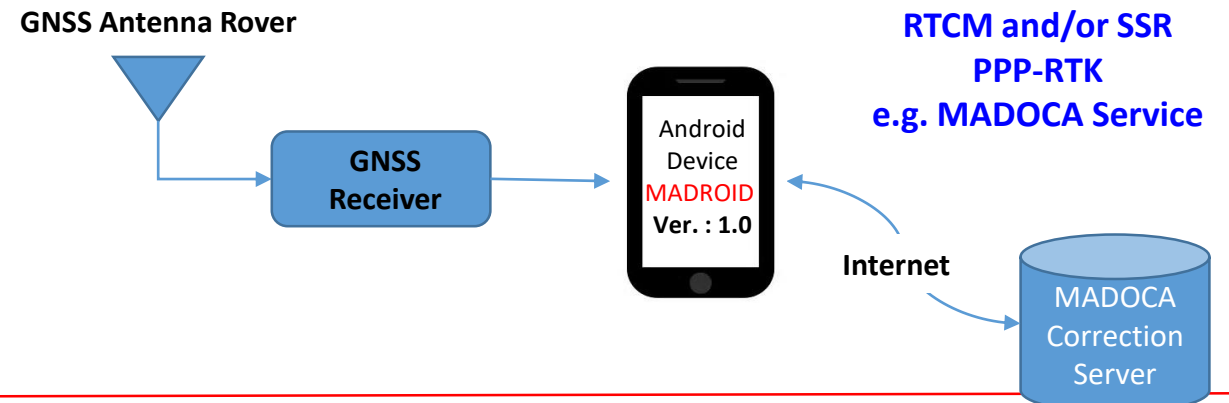
TYPE R2 Type B: Low-Cost, High-Accuracy Receiver System
For Post-Processing & Rover Mode Only



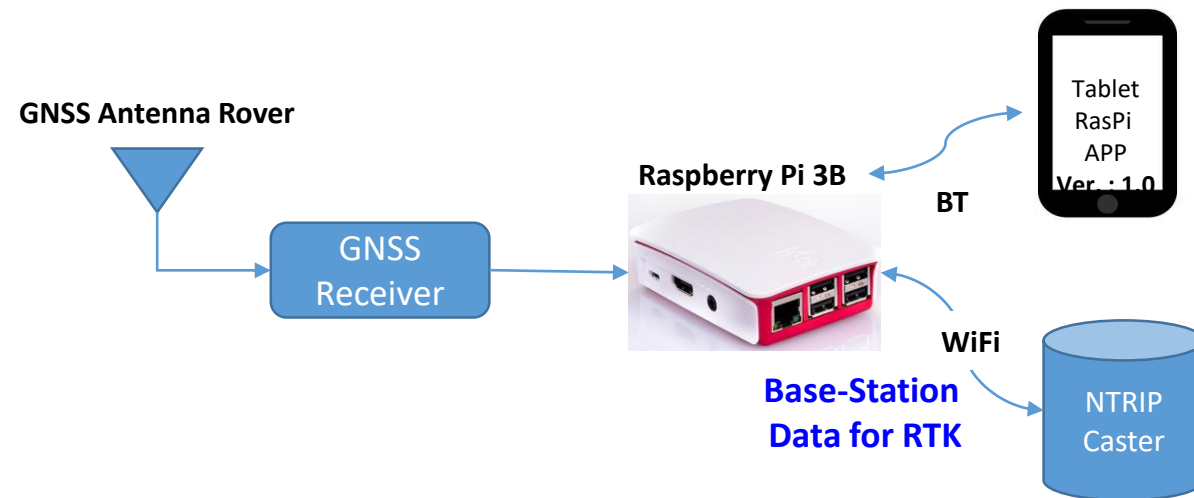
TYPE A1 Type C: Low-Cost, High-Accuracy Receiver System
Real-Time and Post-Processing, Rover Mode Only



TYPE MA Type D: Low-Cost, High-Accuracy Receiver System
Real-Time and Post-Processing, Rover Mode Only

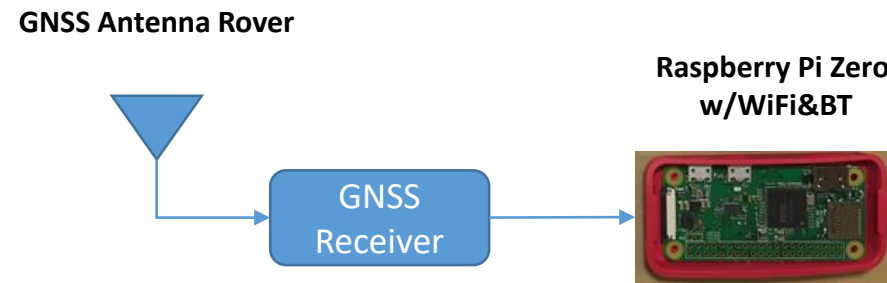


Type – R1: GNSS Receiver with RaspberryPi-3B



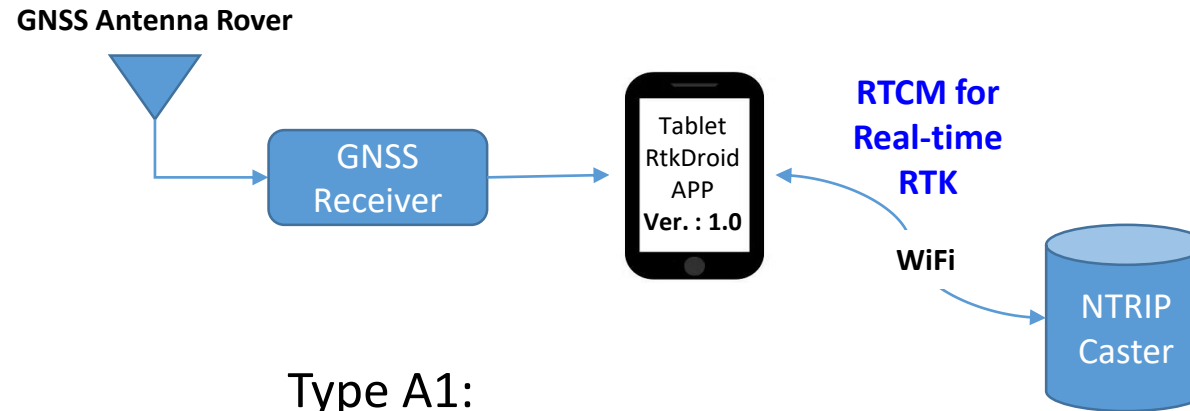
Type R1:
Base or Rover Mode
Real-Time and Post-Processing RTK
Based on RTKLIB Engine

Type – R2: GNSS Receiver with RaspberryPi-Zero/W



Type R2:
Rover Mode
Post-Processing RTK
Log Necessary Raw Data for Post-processing RTK
Based on RTKLIB Engine

Type – A1: GNSS Receiver with Android Device



Type A1:
Rover Mode
Real-Time and Post-Processing RTK
Based on RTKLIB Engine
Real-time processing in Android Device
APP: RTKDroid



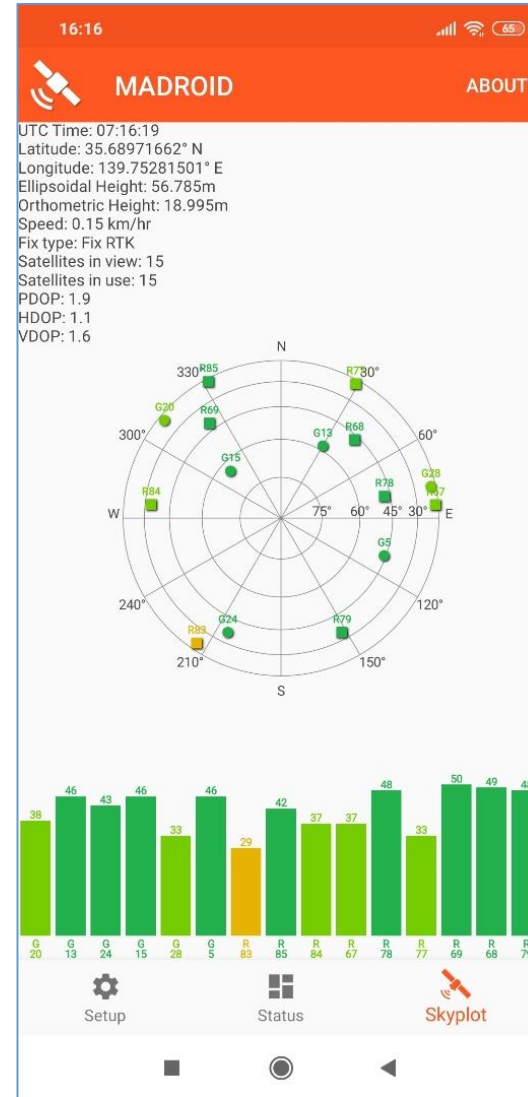
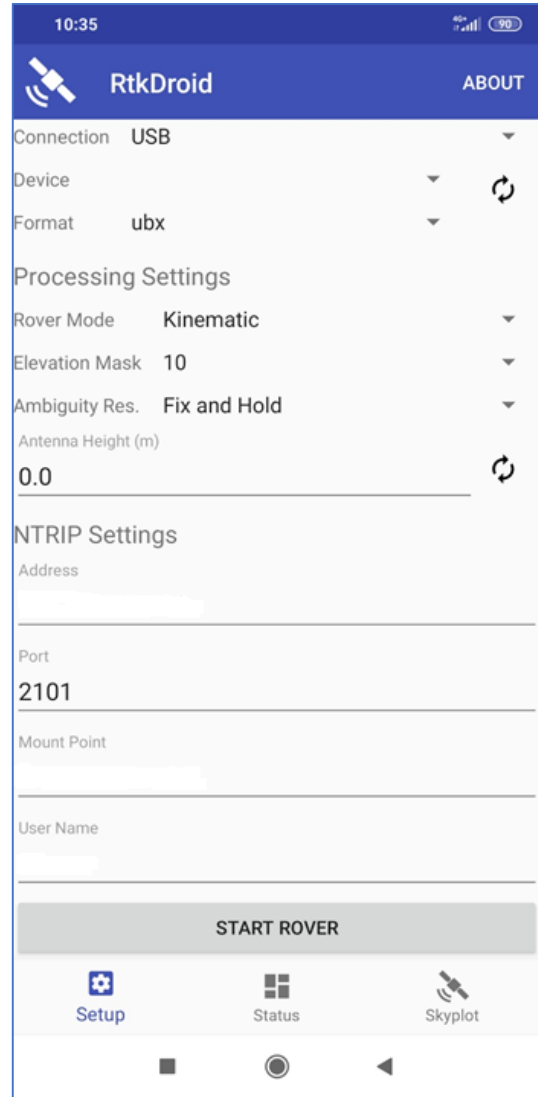
GNSS Receiver Module

Screen Shots of RTKDROID and MADROID

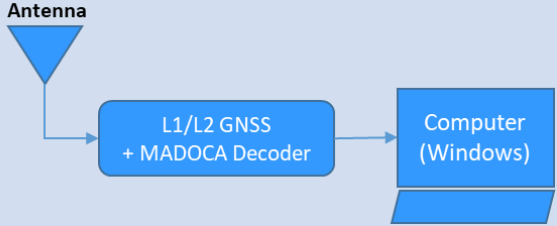
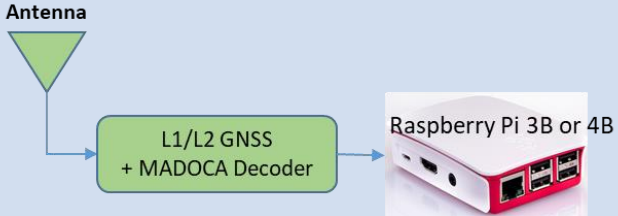
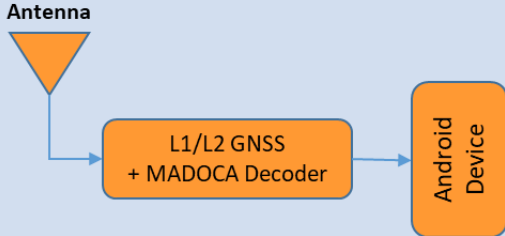
Connect GNSS receiver to
Android device

(1) RTKDROID :
For RTK or PPK

(2) MADROID:
for MADOCA-PPP,
MADOCA-PPP/AR (future)

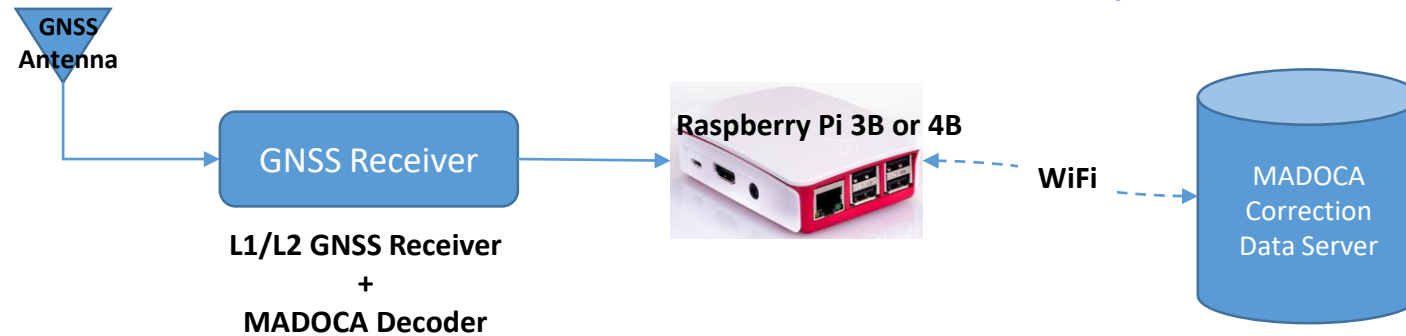


Low-Cost MADOCA Receiver Systems: Product Types

	MAD-WIN	MAD-π	MADROID
Platform / OS	Windows	RaspberryPi 3B or 4B	Android Device
GNSS Receiver	Default : u-blox F9P Other: Any dual-frequency Receiver	Default : u-blox F9P only	Default : u-blox F9P Other: Any dual-frequency Receiver
MADOCA Receiver	U-blox D9 only	U-blox D9 only	NA (MADOCA Online Correction Data only)
GNSS Receiver Data Format	UBX, SBF, RTCM3	UBX SBF, RTCM3 (For online GNSS data)	UBX
MADOCA Correction Data Format (Satellite)	UBX only	UBX only	NA
MADOCA Correction Data Format (Online)	Online Services from GPAS, UTokyo (Test Level) UBX or RTCM3	Online Services from GPAS, UTokyo (Test Level) Online Services UBX or RTCM3	GPAS Services, RTCM3 UTokyo Online Service in the next release
System Architecture			

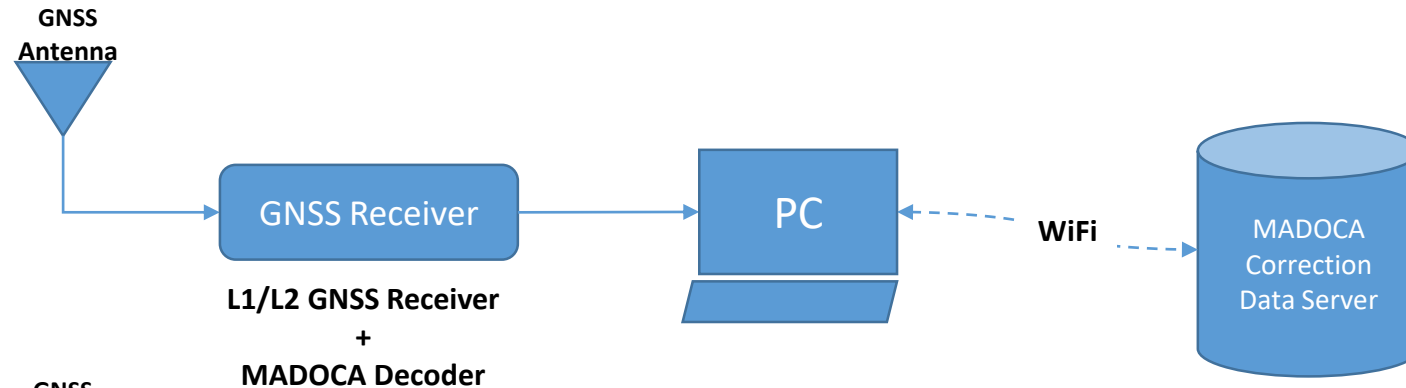
MADOCA Low-Cost Receiver Systems

Type – A : MAD- π



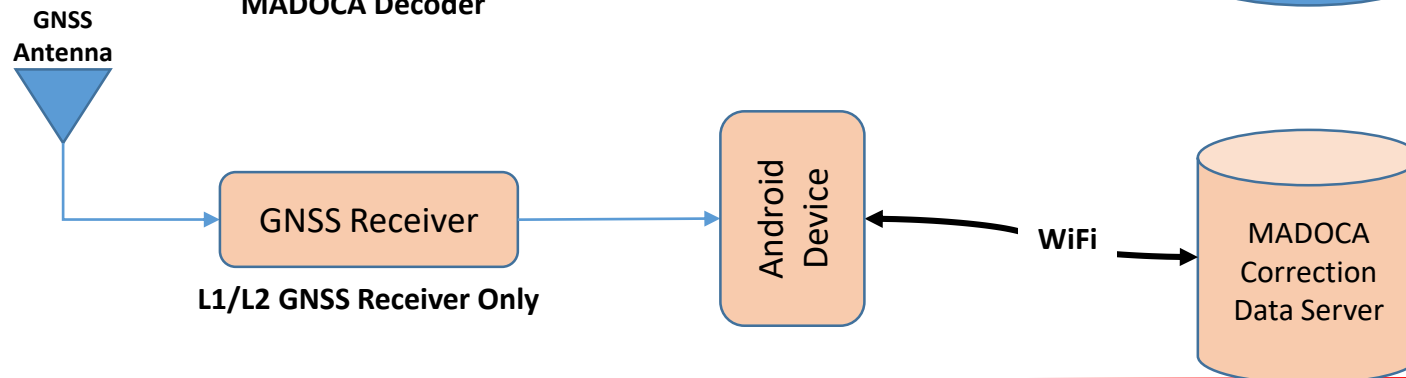
Use MADOCA correction data from server if GNSS receiver does not have MADOCA decoder

Type – B : MAD-WIN



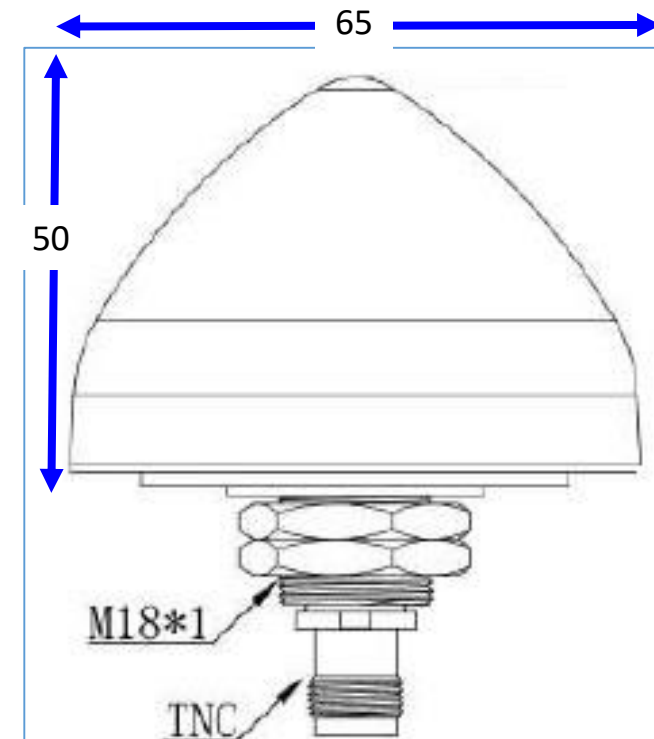
Use MADOCA correction data from server if GNSS receiver does not have MADOCA decoder

Type – C : MADROID

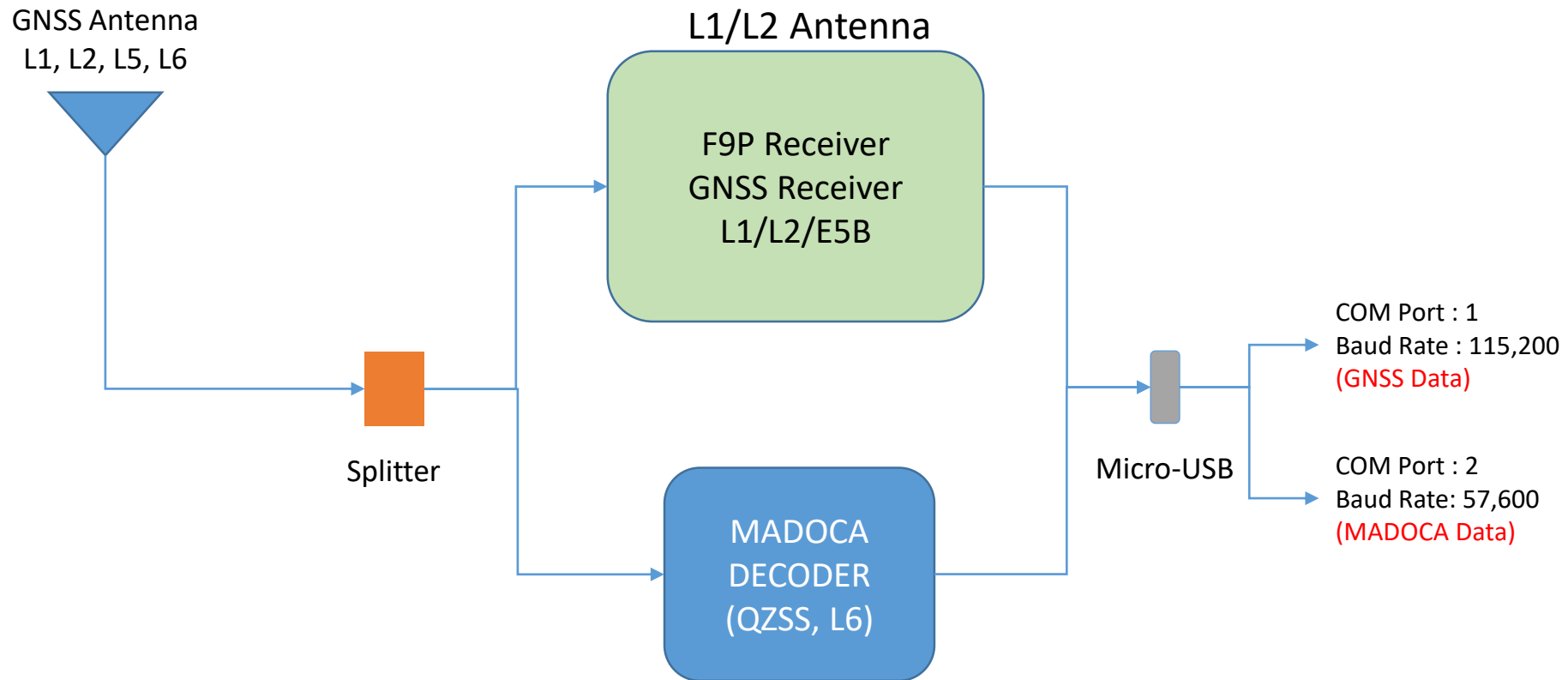


Use MADOCA correction data from server

GNSS MADOCA Receiver and Antenna

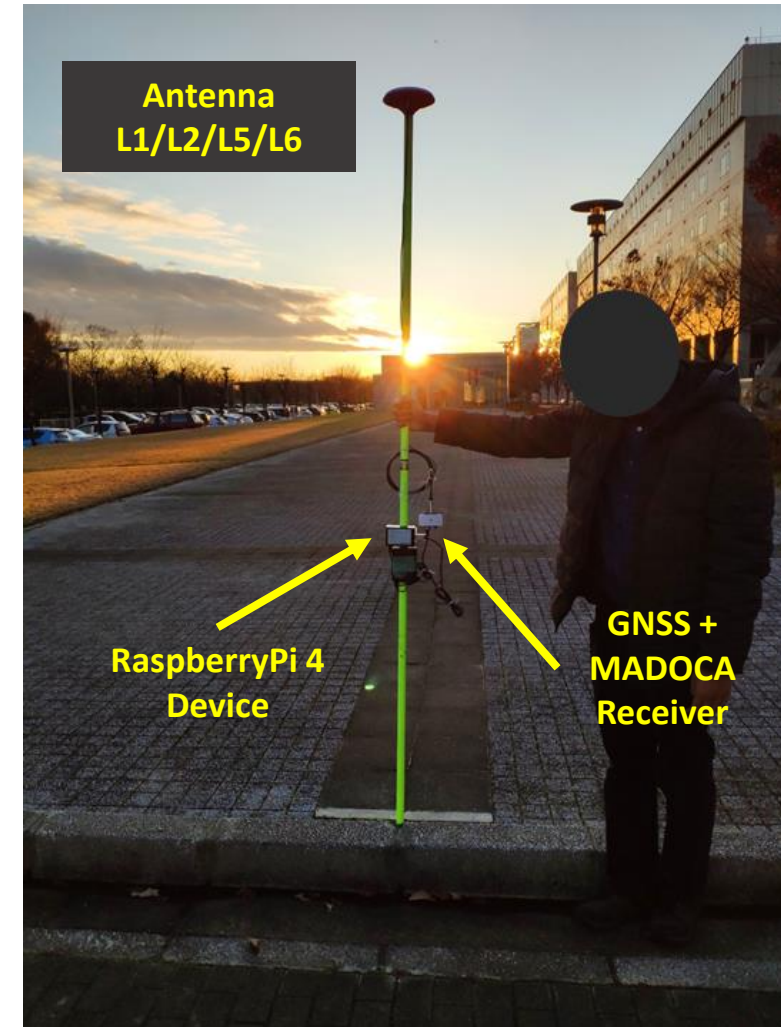


Receiver System Architecture

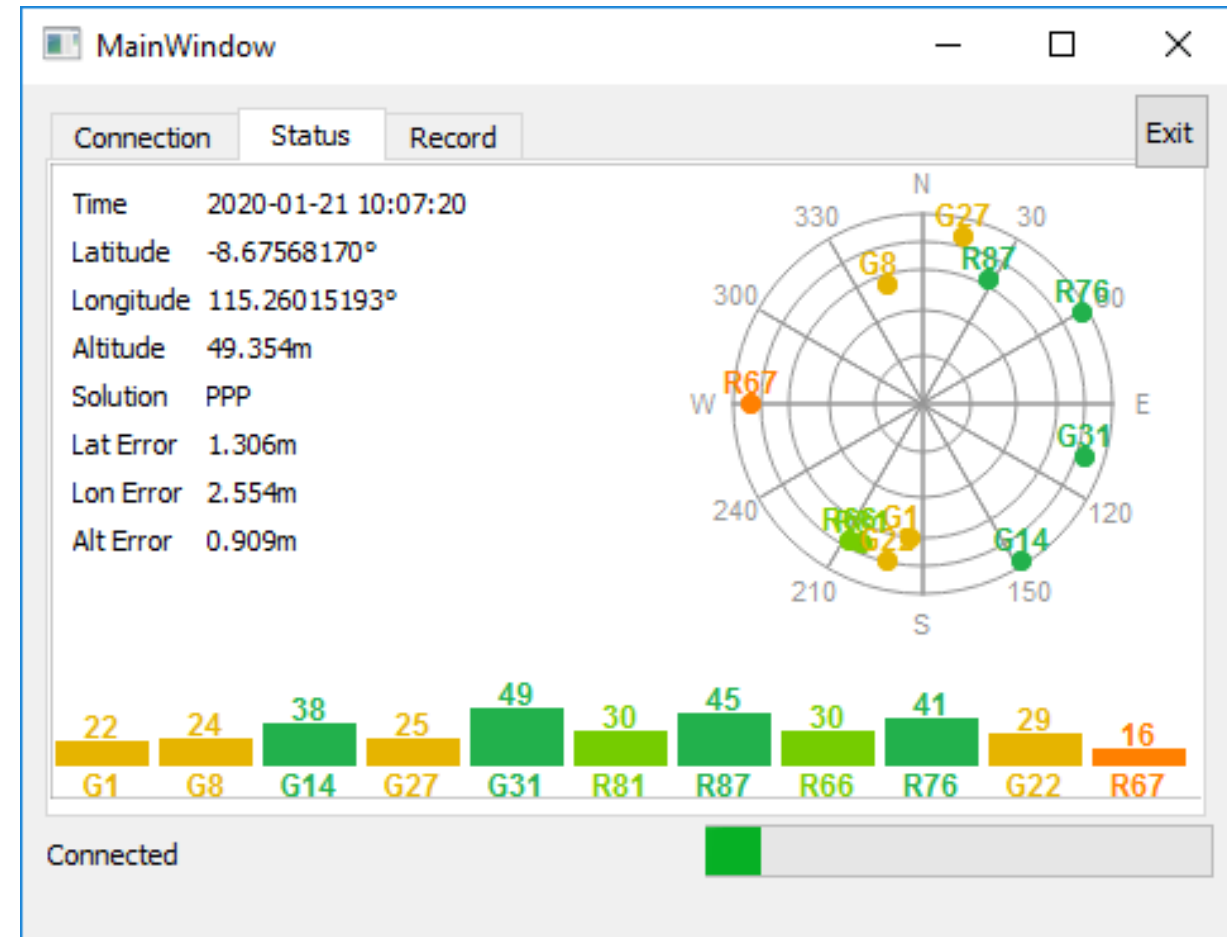
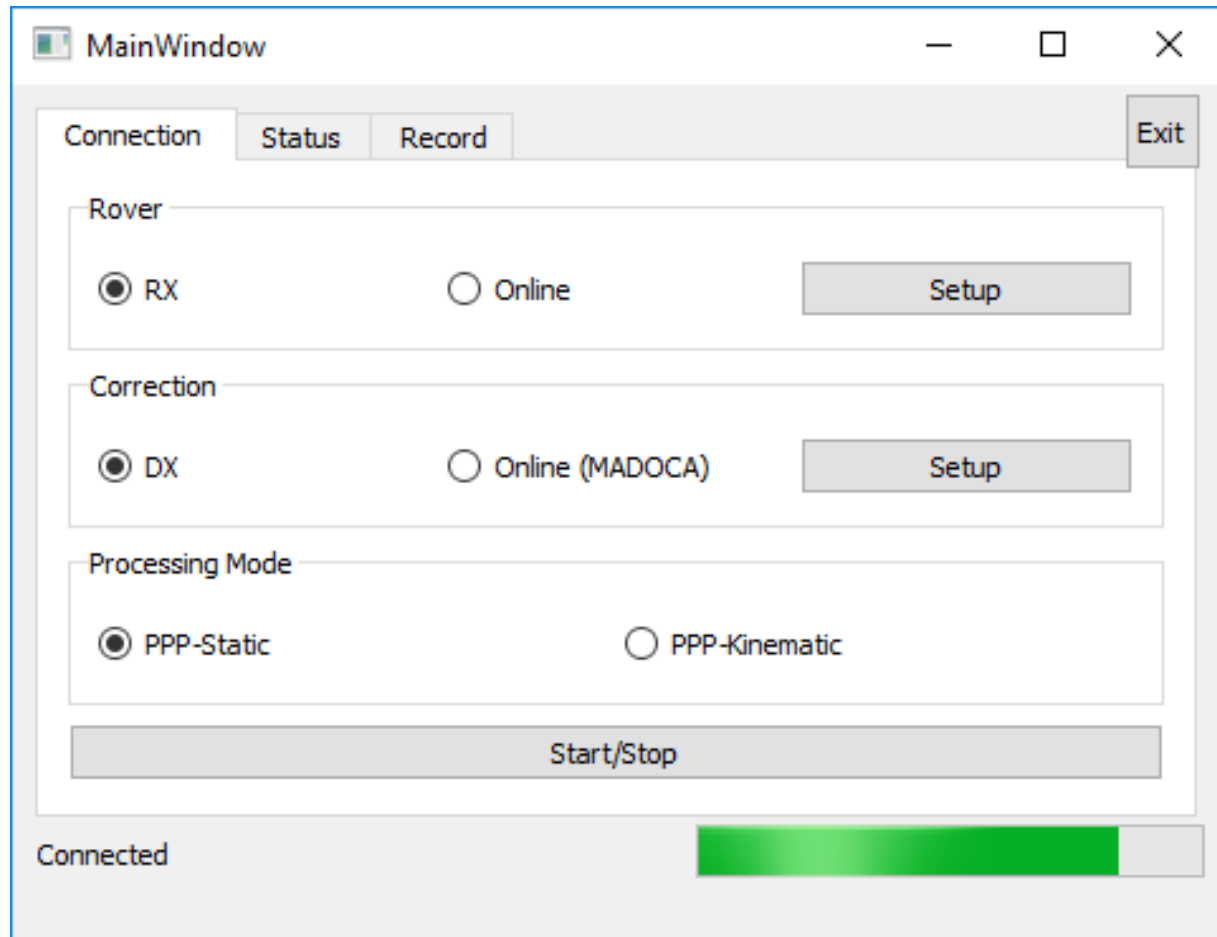


Type A: MAD-PI

MADOCA PPP based on RaspberryPi / Dual Frequency Receiver + MADOCA Decoder



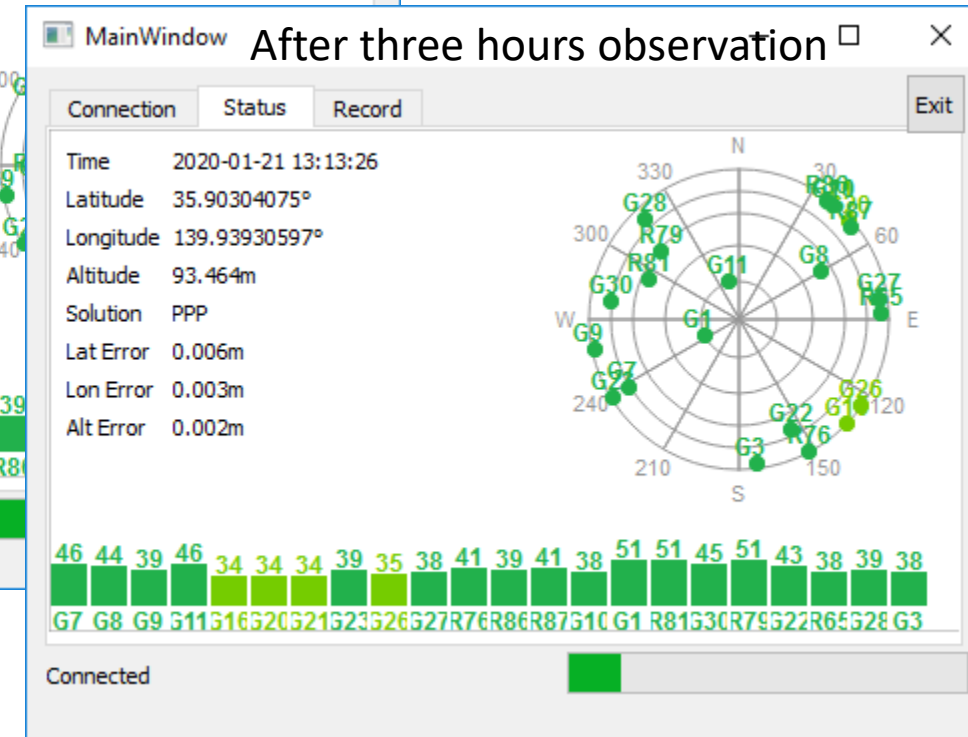
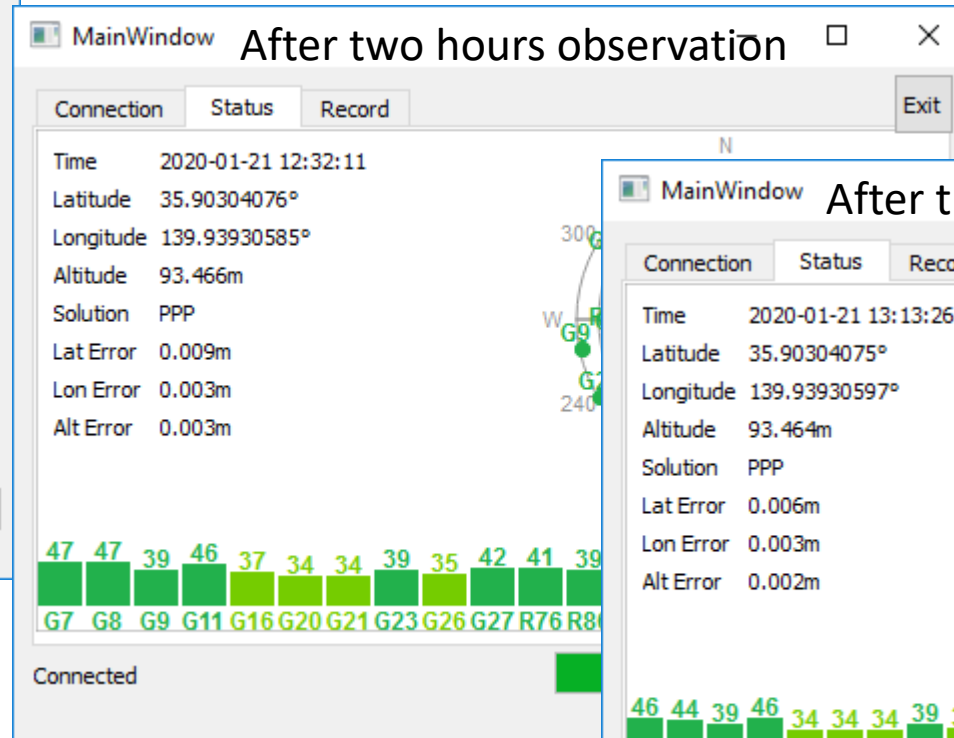
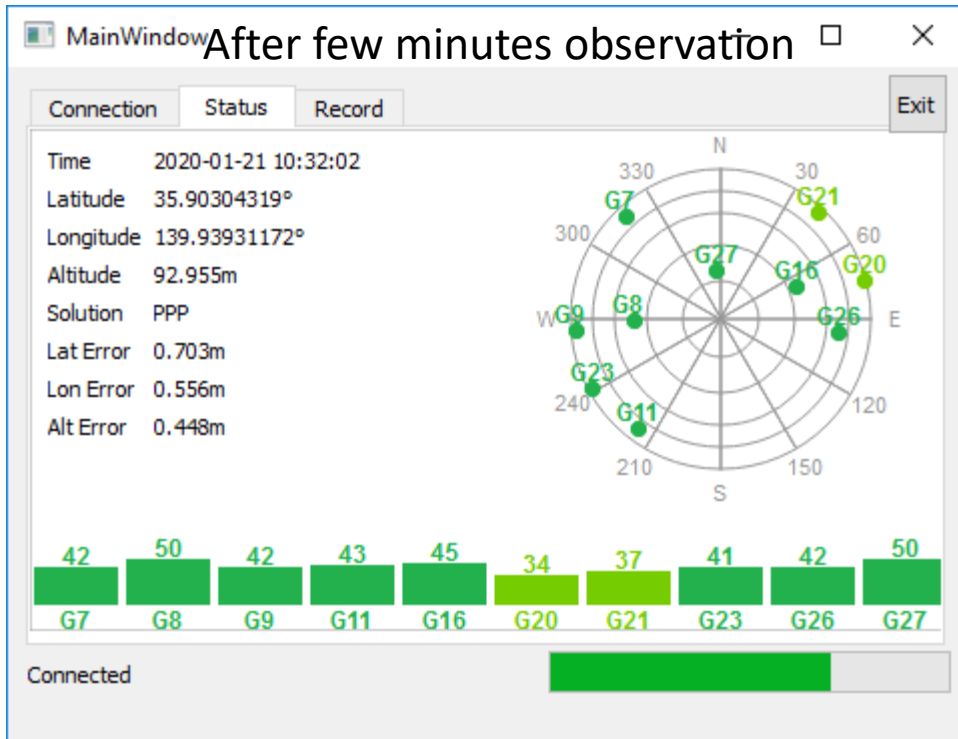
Type B: MAD-WIN



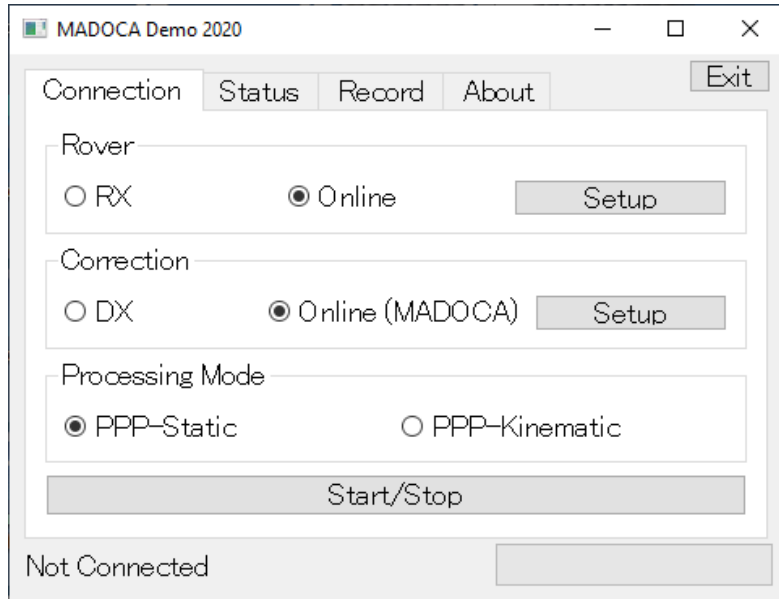
The position accuracy improves to cm (10 – 30 cm) level after initialization time of about 15min.

Type B: MAD-WIN

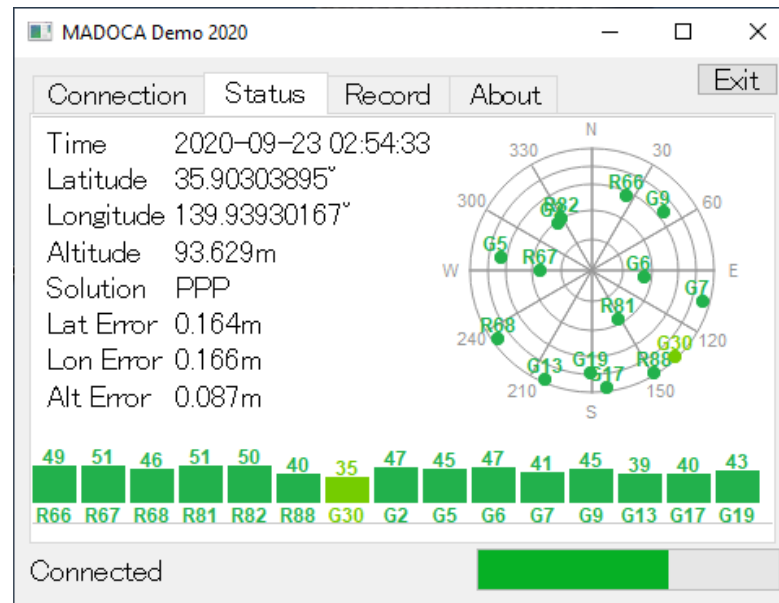
Receiver: Online receiver access in Kashiwa / Correction Data: MADOCA Receiver in Bali



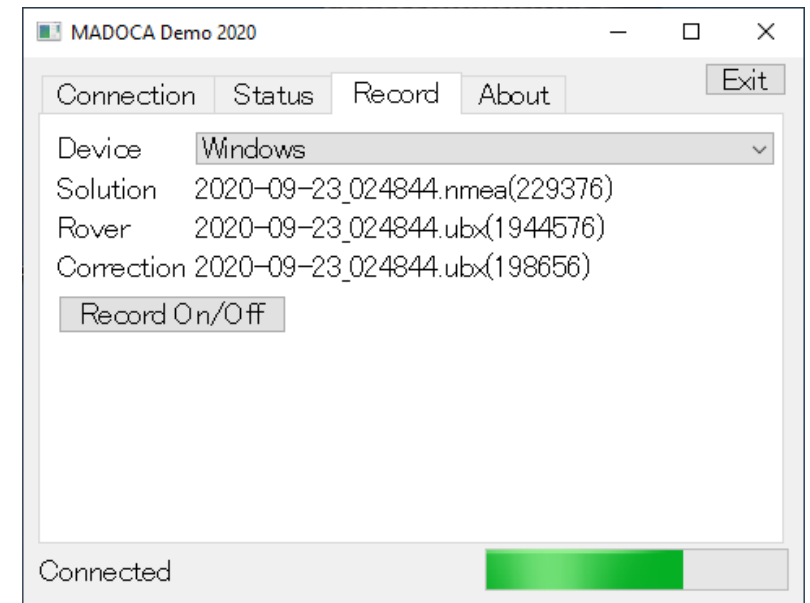
MAD-WIN and MAD- π Screen Shots



Receiver and MADOCA Correction Data Setup Menu

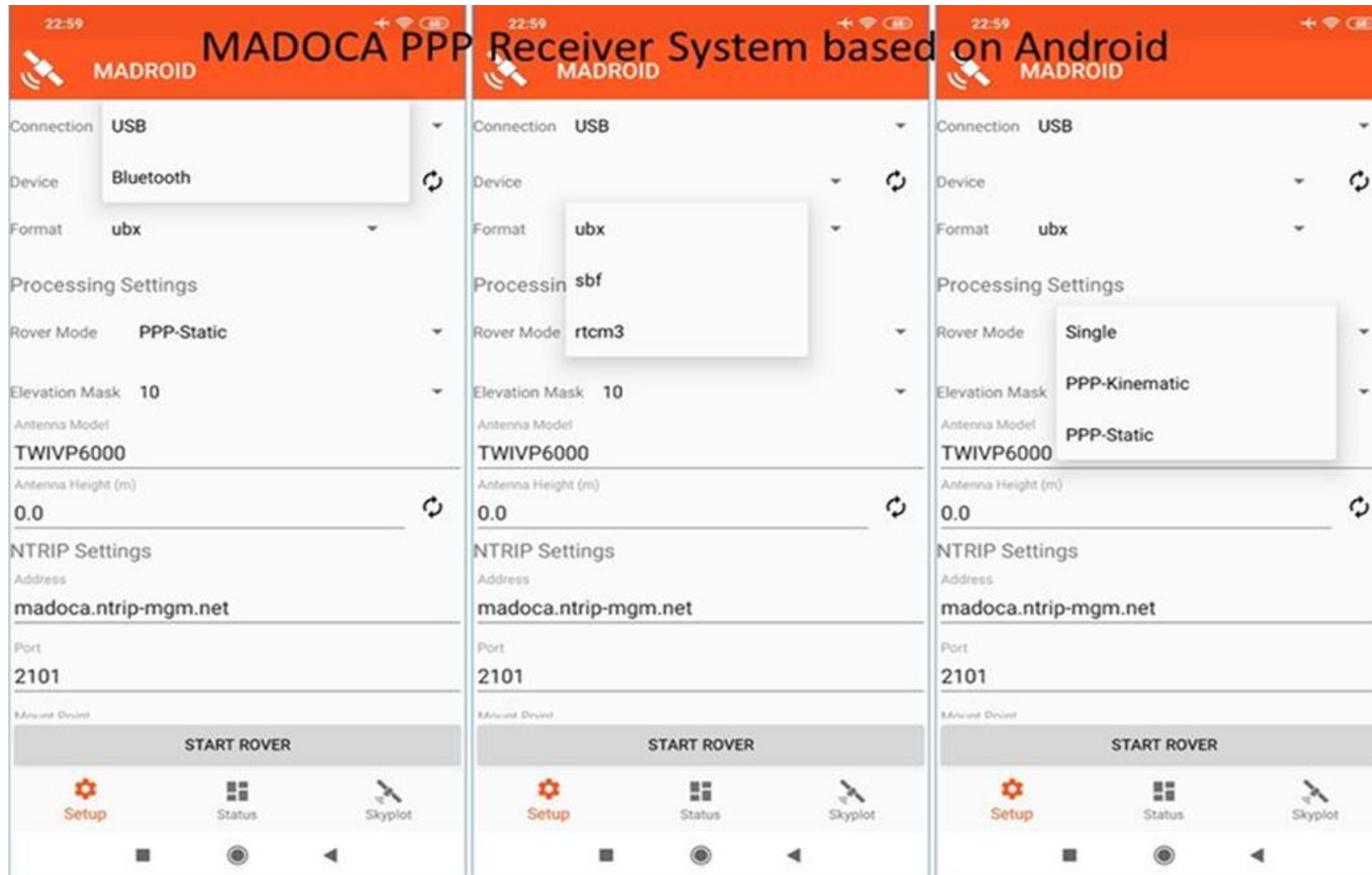


MADOCA PPP Output Display



Log of MADOCA PPP Solution, Receiver Raw Data and MADOCA Correction Data

Type C: MADROID / MADOCA PPP based on Android Dual Frequency Receiver + Online MADOCA Data



Type C: MADROID / MADOCA PPP based on Android

Dual Frequency Receiver + Online MADOCA Data

The image displays three screenshots of the MADROID application interface, which is used for PPP (Precise Point Positioning) based on Android. The interface is divided into three main sections: Setup, Status, and Skyplot.

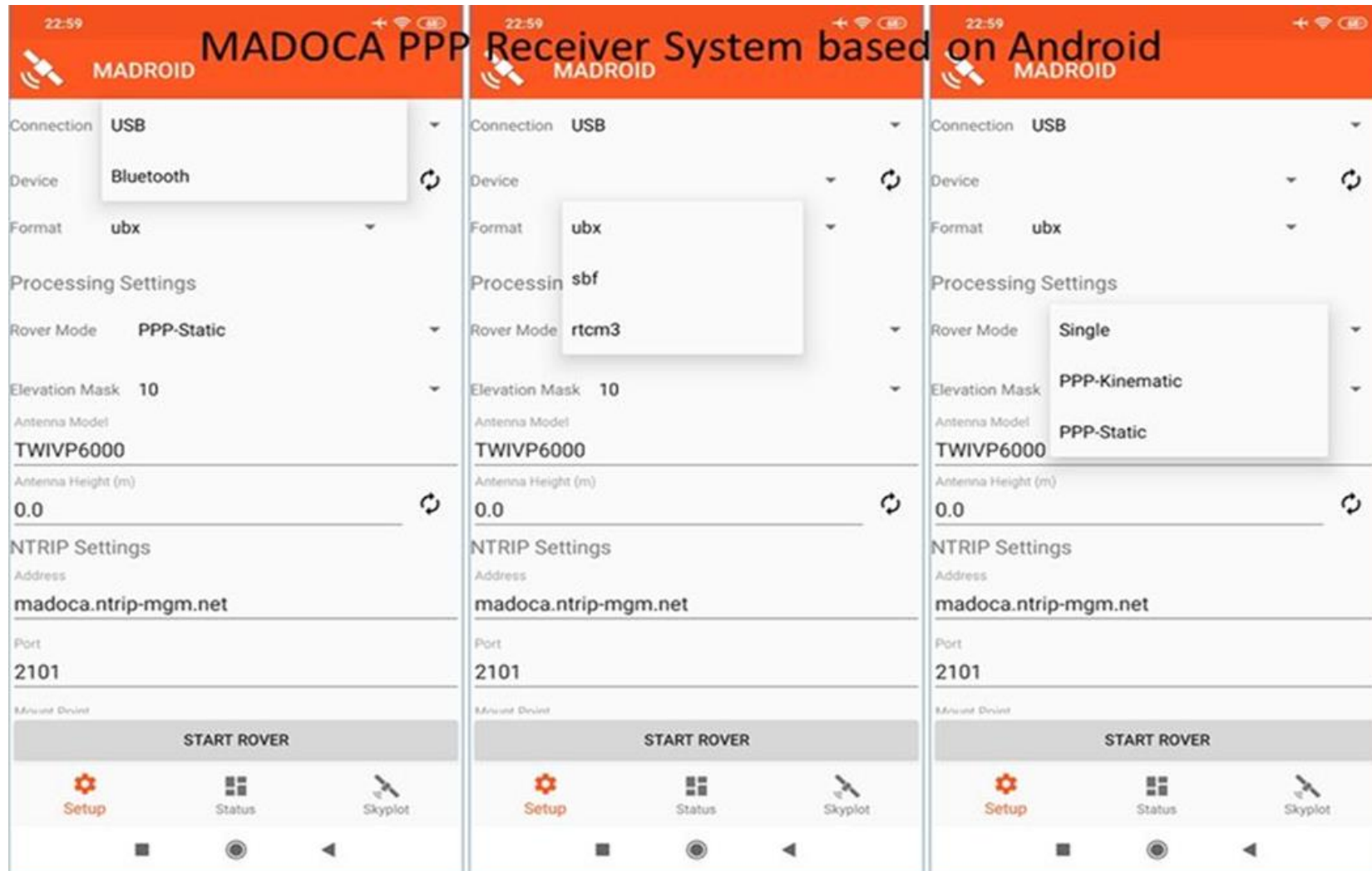
Left Screenshot (Setup): Shows the configuration for the receiver. The connection is USB, the device is a u-blox GNSS receiver, and the format is ubx. Processing settings include a PPP-Static rover mode, an elevation mask of 10, and an antenna model of TWIVP6000. NTRIP settings are configured with the address madoca.ntrip-mgm.net and port 2101. The mount point is MDC0. A "START ROVER" button is visible at the bottom.

Middle Screenshot (Status): Displays real-time data and a skyplot. The UTC time is 05:27:17. The current location is Latitude: 35.90202657° N, Longitude: 139.93857286° E, with an ellipsoidal height of 59.349m and an orthometric height of 21.385m. The speed is 0.15 km/hr, and the fix type is PPP. There are 13 satellites in view and 13 in use. The PDOP is 3.4, HDOP is 1.8, and VDOP is 3.0. The skyplot shows the distribution of satellites in the sky. A bar chart at the bottom indicates the signal strength of the satellites.

Right Screenshot (Recording): Shows the recording status. The date is Dec 25, 2019, and the time is 05:34:17. The current location is Latitude: 35.90202310° N, Longitude: 139.93857932° E, with an X-coordinate of 54N 404216.762m E and a Y-coordinate of 54N 3973601.765m N. The ellipsoidal height is 59.848m and the orthometric height is 21.884m. The speed is 0.11 km/hr, and the fix type is PPP. The PDOP is 3.5, HDOP is 1.9, and VDOP is 3.0. There are 13 satellites in view and 13 in use. The latitude error is 0.191m, the longitude error is 0.171m, and the altitude error is 0.104m. Recording files are listed as NMEA: 2019_12_25_14_28_19.txt (201KB) and UBX: 2019_12_25_14_28_19.ubx (1MB). A "STOP RECORDING" button is visible at the bottom.

MADROID Screenshots

MADOCA PPP based on Android Dual Frequency Receiver + Online MADOCA Data



MADROID Screenshots

MADOCA PPP based on Android Dual Frequency Receiver + Online MADOCA Data

The image displays three screenshots of the MADROID application interface, which is used for MADOCA PPP based on an Android Dual Frequency Receiver.

Left Screenshot (14:34): Shows the configuration screen. The title is "MADROID". The connection is set to "USB". The device is a "u-blox GNSS receiver". The format is "ubx". Under "Processing Settings", the rover mode is "PPP-Static", the elevation mask is "10", and the antenna model is "TWIVP6000". Under "NTRIP Settings", the address is "madoca.ntrip-mgm.net" and the port is "2101". The mount point is "MDC0". A "START ROVER" button is visible at the bottom.

Middle Screenshot (14:27): Shows the real-time status screen. The title is "MADROID". The UTC time is "05:27:17". The location is Latitude: 35.90202657° N, Longitude: 139.93857286° E. The ellipsoidal height is 59.349m and the orthometric height is 21.385m. The speed is 0.15 km/hr. The fix type is "PPP". There are 13 satellites in view and 13 satellites in use. The PDOP is 3.4, HDOP is 1.8, and VDOP is 3.0. A skyplot is displayed, showing the positions of the satellites in the sky. Below the skyplot is a bar chart showing the signal-to-noise ratio (SNR) for each satellite.

Right Screenshot (14:34): Shows the recording screen. The title is "MADROID". The date is "Dec 25, 2019" and the time is "05:34:17". The location is Latitude: 35.90202310°, Longitude: 139.93857932°. The X and Y coordinates are 54N 404216.762m E and 54N 3973601.765m N, respectively. The ellipsoidal height is 59.848m and the orthometric height is 21.884m. The fix type is "PPP". The speed is 0.11 km/hr. The HDOP is 1.9, VDOP is 3.0, and PDOP is 3.5. There are 13 satellites in view and 13 satellites in use. The latitude error is 0.191m, the longitude error is 0.171m, and the altitude error is 0.104m. The NMEA and UBX data files are listed as "NMEA: 2019_12_25_14_28_19.txt(201KB)" and "UBX: 2019_12_25_14_28_19.ubx(1MB)". A "STOP RECORDING" button is visible at the bottom.

MADROID TEST Results : Tokyo

16:16

MADROID ABOUT

Connection USB

Device u-blox GNSS receiver

Format ubx

Processing Settings

Rover Mode PPP-Static

Elevation Mask 10

Antenna Model TWIVP6000

Antenna Height (m) 0.0

NTRIP Settings

Address madoca.ntrip-mgm.net

Port 2101

STOP ROVER

Setup Status Skyplot

16:16

MADROID ABOUT

NTRIP Settings

Address madoca.ntrip-mgm.net

Port 2101

Mount Point MDC0

User Name dinesh@csis.u-tokyo.ac.jp

Password

Use Local Correction

Local Correction Settings

Address 163.43.29.167

Port 80

Mount Point

STOP ROVER

Setup Status Skyplot

16:16

MADROID ABOUT

Mount Point MDC0

User Name dinesh@csis.u-tokyo.ac.jp

Password

Use Local Correction

Local Correction Settings

Address 163.43.29.167

Port 80

Mount Point GPASLOCAL_T2

User Name gpas

Password

STOP ROVER

Setup Status Skyplot

16:16

MADROID ABOUT

UTC Time: 07:16:19
Latitude: 35.68971662° N
Longitude: 139.75281501° E
Ellipsoidal Height: 56.785m
Orthometric Height: 18.995m
Speed: 0.15 km/hr
Fix type: Fix RTK
Satellites in view: 15
Satellites in use: 15
PDOP: 1.9
HDOP: 1.1
VDOP: 1.6

STOP ROVER

Setup Status Skyplot

16:16

MADROID ABOUT

Date: Sep 15, 2020
Time: 07:16:23
Latitude: 35.68971663°
Longitude: 139.75281501°
X: 54N 387152.640m E
Y: 54N 3950250.977m N
Ellipsoidal Height: 56.780m
Orthometric Height: 18.990m
Fix Type: Fix RTK
Speed: 0.09 km/hr
HDOP: 1.1
VDOP: 1.6
PDOP: 1.9
Satellites in View: 15
Satellites in Use: 15
Latitude Error: 0.065m
Longitude Error: 0.055m
Altitude Error: 0.028m

NMEA: 2020_09_15_16_08_35.txt(279KB)
RAW: 2020_09_15_16_08_35.ubx(2MB)

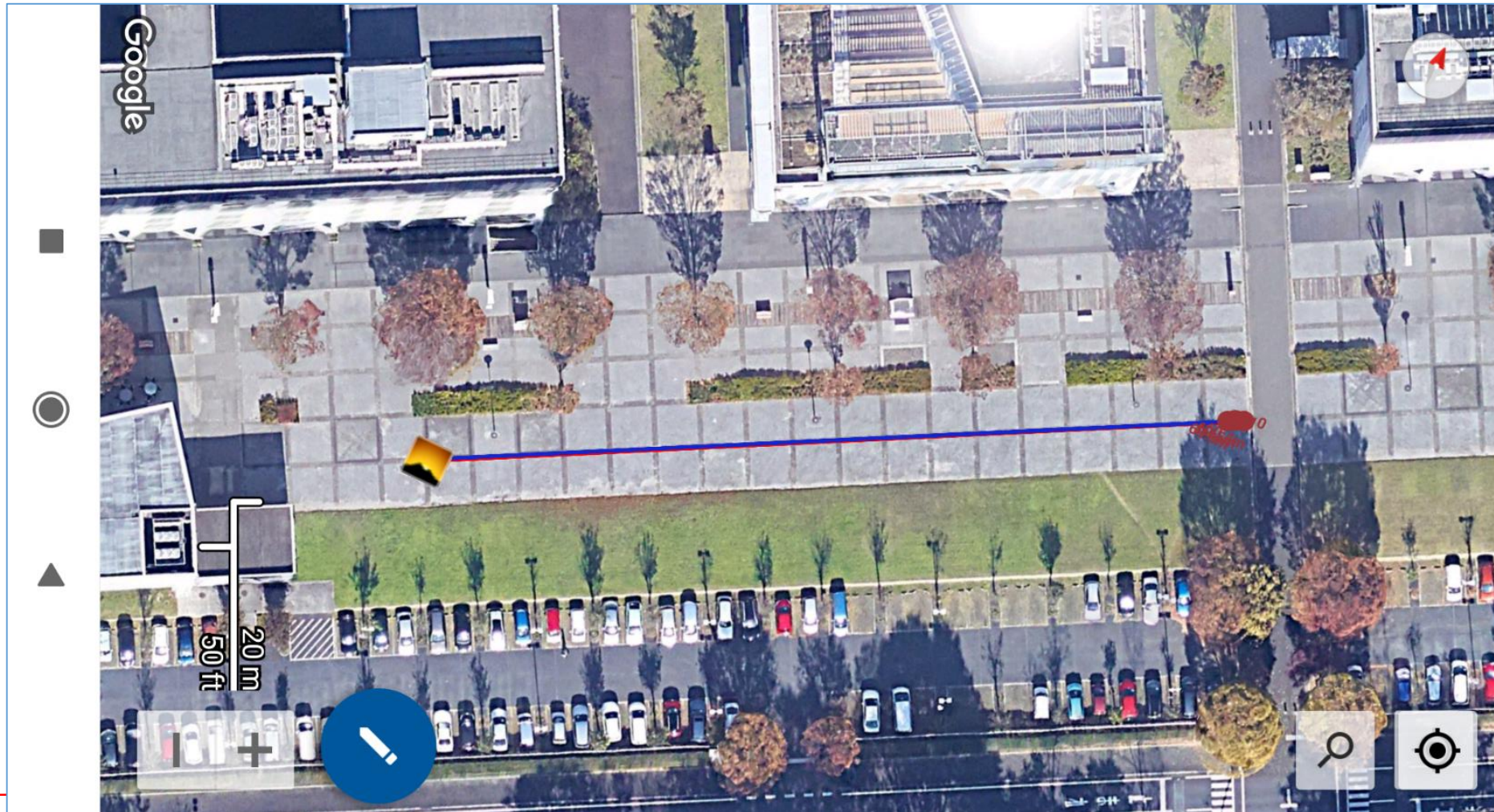
STOP RECORDING

Setup Status Skyplot

Position Data from MADOCA PPP

We walked straight along the concrete tiles (30cmx30cm) and PPP results showed perfect straight line. Accuracy is about 15cm.

Receiver : F9 + Online MADOCA Correction Data



Contact and Additional Information

- Homepage

- Main Page : <https://home.csis.u-tokyo.ac.jp/~dinesh/>
- Webinar Page : <https://home.csis.u-tokyo.ac.jp/~dinesh/WEBINAR.htm>
<https://gnss.peatix.com/>
- Training Data Etc : https://home.csis.u-tokyo.ac.jp/~dinesh/GNSS_Train.htm
- Low-Cost Receiver : <https://home.csis.u-tokyo.ac.jp/~dinesh/LCHAR.htm>
- Facebook : <https://www.facebook.com/gnss.lab/>

- Contact

- E-mail : dinesh@csis.u-tokyo.ac.jp
- Skype : mobilemap